[C A S E   R E P O R T]

Ferrofluid-associated Cutaneous Dyschromia

Discoloration of Hand and Fingers Following Accidental Exposure to Ferromagnetic Fluid

[a]PHILIP R. COHEN, MD; [b,c]KENNETH S. ARFA, MD

[a]Department of Dermatology, University of California San Diego, San Diego, California; [b]The University of Houston Health Center, University of Houston, Houston, Texas; [c]Private Practice, Bellaire, Texas

ABSTRACT

Background: Ferrofluid is a colloidal suspension that usually consists of surfactant-coated nanoparticles of magnetite (Fe_3O_4) in a carrier liquid. Ferromagnetic fluid forms spikes when the liquid is exposed to a magnetic field. **Purpose:** The authors describe a man who developed temporary discoloration of his right palm and fingers after accidental cutaneous contact with ferrofluid and discuss some of the current and potential applications of this unique liquid. **Methods:** A 28-year-old man was evaluating the effects of magnetic fields using ferrofluid. He performed a modification of the "leaping ferrofluid" demonstration in which he held a superstrong (14,800 gauss magnetic field strength) N52 rare earth neodymium magnet in his palm and slowly lowered that hand over an open bowl that was filled with ferrofluid. **Results:** As the magnet approached the liquid, the ferrofluid became magnetized. The liquid leaped from the bowl and contacted not only the magnet, but also the palmar surface of his hand and fingers, resulting in a black-brown dyschromia of the affected skin. The discoloration completely resolved after two weeks without any adverse sequellae. **Conclusion:** Ferrofluid has numerous current and potential applications; in addition to being of value educationally and aesthetically (after being subjected to magnetic fields), it is also utilized for audio loudspeakers, medical innovations (such as a component of either a research tool, a diagnostic aid, or a treatment modality), and seals. Although the authors' patient did not experience any acute or chronic toxicity from his cutaneous exposure to ferrofluid, conservative follow-up for individuals who experience skin contact with ferromagnetic fluid may be appropriate. (*J Clin Aesthet Dermatol.* 2016;9(3):51–54.)

Ferrofluid consists of surfactant-coated ferromagnetic nanoparticles suspended in a carrier fluid (Figure 1).[1] The surface of the ferromagnetic fluid forms a pattern of peaks and valleys when the liquid is subjected to a magnetic field (Figure 2).[1,2] The authors describe a man who developed temporary hyperpigmentation of his ventral hand and fingers after accidental exposure to ferrofluid.

CASE REPORT

A 28-year-old healthy Caucasian man presented for evaluation of a recently acquired discoloration of his right hand and fingers. The day before, he had been experimenting with ferrofluid (magnetite [3–15% by volume], oil-soluble dispersant [6–30%], and carrier liquid [55–91% by volume]) (Ferrotec Corporation, Santa Clara, California) using a 14,800 gauss (magnetic field strength) N52 2x2x1-inch superstrong rare earth neodynium magnet (Figure 3). He held the square magnet in his right palm. Initially, the magnet was placed beneath the plastic bowl that contained the ferrofluid (Figure 4); the liquid was influenced to form spikes along the magnetic field lines (Figure 5). Subsequently, he decided to lower his ventral right hand (with the exposed magnet in his palm) over the open ferrofluid-containing bowl. Similar to "leaping ferrofluid" demonstration described by Berger et al,[1] the ferrofluid became magnetized and moved upward from the bowl to contact both the magnet and the palmar surface of his hand and fingers.

Cutaneous examination showed an asymptomatic black-brown macular discoloration on the distal ventral right hand and the proximal 2nd, 3rd, 4th, and 5th digits (Figure 6). The splash pattern of pigmentation spared the central palm where the square magnet had been located. Initially, the dyschromia persisted after repeated hand washing with soap and water. However, the dark areas slowly faded and the discoloration resolved after two weeks (Figure 7).

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ADDRESS CORRESPONDENCE TO: Philip R. Cohen, MD; Email: mitehead@gmail.com

Figure 1. Ferrofluid appears as a flat-surfaced black liquid in the plastic bowl.

Figure 2. A distinctive pattern of peaks and valleys are produced when the ferrofluid is exposed to a magnetic field.

Figure 3. A square 2x2x1 inch N52 super-strong rare earth neodymium magnet with a magnetic field strength of 14,800 gauss.

Figure 4. Ferrofluid spikes begin to form as the bottom of the ferrofluid-containing plastic bowl is held above and slowly lowered toward the underlying magnet.

Figure 5. The borders of the square magnet can be observed after the ferrofluid-containing plastic bowl has been placed on top of the magnet.

DISCUSSION

In the 1960s, National Aeronautic Space Agency scientists were studying different methods for controlling liquids in space. One of the in-vestigators, Stephen Pappell, is credited with developing and clas-sifying ferrofluid. Ferromagnetic fluid was classified as a superparamagnet since, in the absence of an externally applied magnetic field, it does not retain magnetization.[1]

Ferrofluid is a colloidal sus-pension and thereby has the properties of two states of matter: The magnetic properties of the solid metal and the fluid properties of the liquid it is in. They consist of nano-sized magnetic particles that are coated with a surfactant to prevent clumping and suspended in a carrier fluid. The particles are usually 10 nanometers or less in diameter and composed of an iron-containing compound, such as magnetite (Fe_3O_4). The carrier fluid is usually water or an organic solvent and the choice of surfactant depends on whether the ferrofluid is aqueous, oil, or liquid metal based.[1,2]

Ferrofluid was initially used in satellites to seal the rotating shafts.[1] The advantages of ferromagnetic fluid was readily observed. First, the application of a magnetic field could precisely control the location of the fluid. And second, the fluid could be forced to flow by varying the strength of the magnetic field.[2]

A regular formation of peaks and valleys is created when ferrofluid is subjected to a magnetic field (Figure 8). The field lines run through the liquid and the magnetic energy attempts to extend the fluid spikes as far as possible into the air above. However, gravity and surface tension limit the formation of the liquid peaks and valleys.[1,2] Indeed, ferrofluid is a superlative teaching aid for demonstrating the effects of magnetic fields.[3] The patient's temporary staining of his palm and fingers accidentally occurred when he was evaluating the response of ferrofluid to a powerful hand-held magnet.

The current utilization of ferrofluid is diverse. It is commonly used in the production of seals that protect against gas, vapor, and other contaminants while providing virtually no friction between the rotating and stationary components. Ferrofluid seals are used around the spinning drive shafts in hard disks. They are also incorporated into the manufacture of semiconductors where rotation is required in either critical gas environments, or high temperature applications, and/or vacuum processes.[2,3] Ferrofluid is also frequently used to improve the performance of audio loudspeakers; the liquid not only dampens unwanted vibration and resonance, but also provides cooling by removing heat from the voice coil.[1–3]

Figure 6. A distant view of the ventral surface of the right and left hands shows discoloration of the distal right palm and proximal fingers; the right hand shows sparing of the dyschromia in the central right palm which corresponds to the area covered by the square magnet that was being held above the ferrofluid.

Figure 7. Two weeks after cutaneous exposure to the ferromagnetic fluid, the right palm and ventral fingers show complete resolution of ferrofluid discoloration and appear similar in color to the left hand.

Biomedical applications of ferrofluid include its use either as a research tool (for chromatography, immunoassays, and molecular diagnostics),[3] a diagnostic aid (in magnetic resonance imaging),[2,4,5] or a potential therapeutic treatment modality (as a component of targeted therapy for tumor ablation in oncology patients receiving cytotoxic agents or hyperthermia).[6–10] In addition, the aesthetic appearance of the liquid (after being influenced by magnets) has been incorporated in the presentations of artists and the music videos of musicians. Another unique use of ferrofluid is its incorporation into magnetic ink that is then used for printing United States paper currency; identification of a non-counterfeit dollar bill is demonstrated by the attraction of the genuine currency to a very strong magnet when the magnet is brought near the money.[1]

The toxicity of ferrofluid is very low; animal experiments in which the permissible maximum doses of ferrofluid were either administered orally, intravenously, or intraperitoneally did not kill the mice.[12] However, earlier investigators had noted that animal subjects (male Sprague-Dawley rats and male athymic nude mice) that received ferrofluid in the supraphysiological dose range developed lethargy for 12 to 24 hours, resistance of food uptake, and persistent discoloration for about one week; the later change was attributed to the relatively enormous iron load.[13] Safety precautions for humans working with ferrofluid comment that prolonged or repeated contact with skin or eye may cause irritation, and inhalation of mist or vapor at high temperature may irritate respiratory passages; it is also recommended not to induce vomiting, but to seek medical attention, if the ferrofluid is ingested.[14]

The etiology of the patient's dyschromia remains to be determined. Although the authors postulate that the dyschomia is secondary to the iron in the ferrofluid, it is possible that his cutaneous staining could have resulted from either the carrier fluid, the surfactant used in the fluid, and/or even an oxidative reaction with other components of his skin. Evaluation of a lesional skin biopsy from discolored skin—stained with not only hematoxylin and eosin stains, but also a Perl's Prussin blue stain for iron—may be helpful to establish the pathogenesis of ferrofluid-associated cutaneous dyschromia.

The patient's slowly resolving cutaneous dyschromia is similar to the fading observed following the application of a henna tattoo. However, in contrast to the adverse sequelae that can potentially be associated with temporary henna tattoos (such as allergic contact dermatitis),[11] the authors' patient did not develop any acute or chronic side effects from the contact of ferrofluid with his skin. Although the authors were not able to find any similar reports of cutaneous ferrofluid exposure,

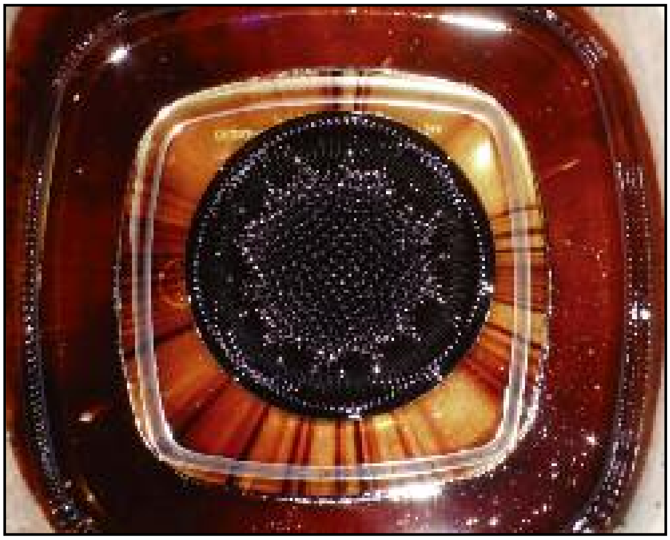

Figure 8. A magnetic field influences the ferrofluid to form peaks and valleys; the fluid spikes that extend from the surface of the liquid into the air above are created by the magnetic energy (directed upward through the fluid) and limited by the surface tension of the liquid and the downward force of gravity.

based on the information provided in the material safety data sheet from a ferrofluid company,[14] the authors conservatively recommend that diligent initial observation and subsequent periodic follow-up may be warranted for individuals experiencing accidental contact of ferrofluid with their skin.

CONCLUSION

Ferrofluid is a superparamagnet colloid suspension usually consisting of magnetite (Fe_3O_4) nanoparticles that are coated with a surfactant and suspended in a carrier protein. Exposure of ferrofluid to a magnetic field results in the formation of ferrofluid spikes that extend upward from the liquid's surface into the air above. The following opposing forces influence the pattern of peaks and valleys: 1) magnetic energy and 2) gravity and the surface tension of the liquid. Ferrofluid has numerous current and potential applications; in addition to being of value educationally and aesthetically (after being subjected to magnetic fields), it is also utilized for audio loudspeakers, medical innovations (such as a component of either a research tool, a diagnostic aid, or a treatment modality), and seals. The authors' patient developed a temporary dyschromia of his right hand following nonintentional contact with ferrofluid; the discoloration slowly faded and completely resolved without any adverse sequelae during the two weeks after his accidental exposure to the liquid. Although the patient did not experience any acute or chronic toxicity from his cutaneous exposure to ferrofluid, conservative follow-up for individuals who experience skin contact with ferromagnetic fluid may be appropriate.

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